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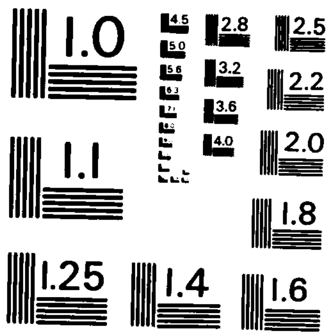

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RANRL TECHNICAL MEMORANDUM (EXTERNAL)

No. 2/85

Proposal For a small Drifting Buoy System of Long Life by utilizing Wave Power.

M. de SOUSA

FEBRUARY 1985

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ABSTRACT

The motion of a buoy system made up of a spar and toroid float is used to drive a linear induction generator.

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PROPOSAL FOR A SMALL DRIFING BUOY SYSTEM OF LONG LIFE BY UTILIZING WAVE POWER

1. INTRODUCTION

Most buoy systems rely on storage batteries to power any instrumentation or sensors. They are generally of limited life unless some method of recharging the batteries is utilized. One standard method is by using solar cells. Energy obtained from them is limited by the weather, the available surface area and fouling. The method proposed in this memo is to use wave action to generate power through a linear induction generator. The type of wave action considered is small waves of amplitudes less than a few feet. The benefits of using this source of energy is that it does not suffer from biofouling or cloudcover and it is generally available 24 hours a day since a dead calm sea with little or no wave motion is rare.

2. DESCRIPTION

The main part of the buoy is a central thin spar with an antenna (if required) and a coil. Fitting around the central spar is a toroid float in which is housed a permanent magnet located opposite the coil on the spar. The toroid float is attached to the spar via a spring system, in this case a disc in which eight fingers have been cut, four are attached to the toroid float and four to the spar. This gives a double cantilever spring effect.

The purpose of the arrangement is to allow the toroid float to oscillate vertically relative to the spar utilizing the magnet and the coil to produce electric power as a linear inductance generator (Figure 2). The toroid float will respond readily to surface waves of small amplitude while the spar would have a much reduced response enabling electrical energy to be produced from the mechanical action of the waves.

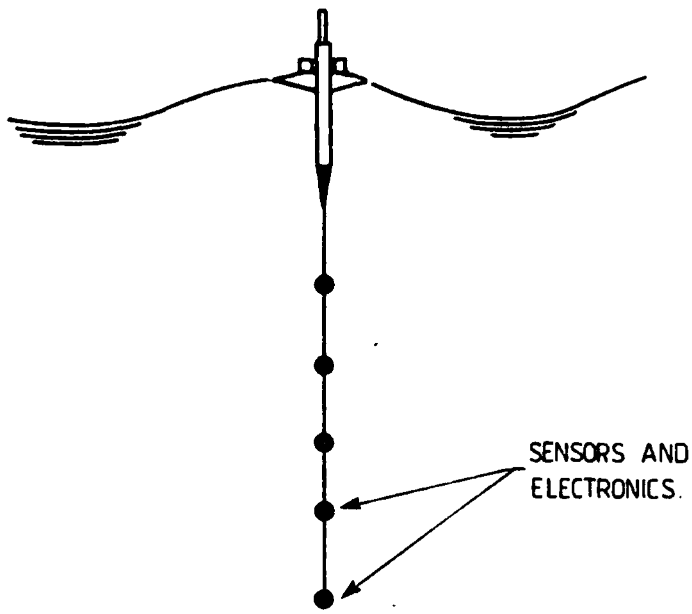
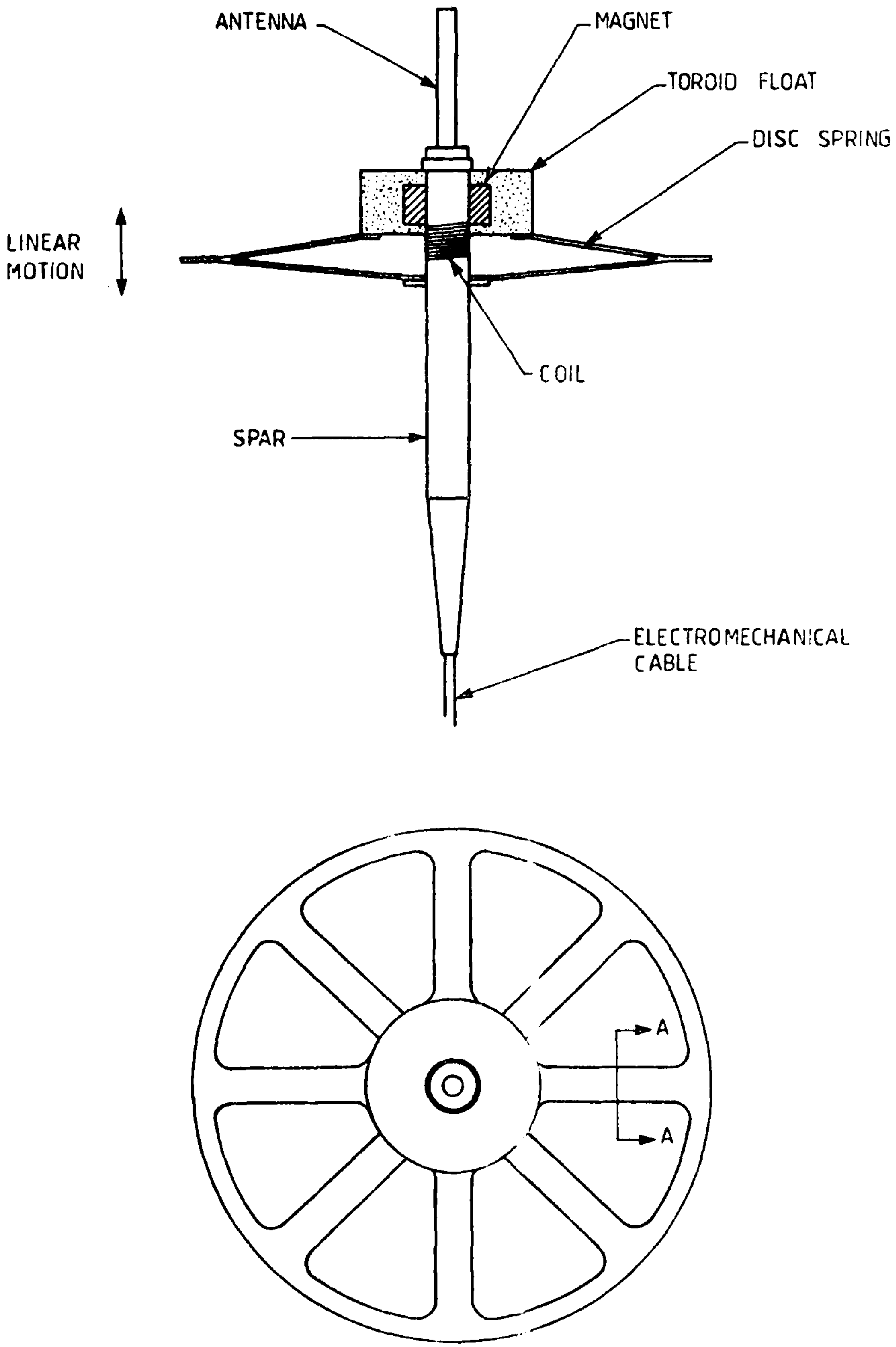


Fig. 1. Drifting system utilizing wave action for power generation.



ANTENNA
MAGNET
TOROID FLOAT
DISC SPRING
LINEAR MOTION
COIL
SPAR
ELECTROMECHANICAL CABLE
A
A

Fig. 2.

3. LINEAR INDUCTANCE GENERATOR

In order to make some theoretical determination of the power from the linear induction generator the wave action can be assumed to be sinusoidal of constant amplitude and frequency.

The magnet motion would respond to the wave action in the form

$$Z = Z_0 \cos(\omega t + \gamma - \sigma_z)$$

where ω - circular wave frequency

Z_0 - magnet motion amplitude

γ - phase angle dependent on the wave force components

σ_z - phase angle primarily dependent on the system damping factor

The coil motion would respond in the form

$$X_e = X_0 \cos(\omega_e t + \phi_e)$$

ϕ_e - phase angle

X_0 - coil motion amplitude

Relative motion $\xi = Z - X_e$

and $\dot{\xi} = \dot{Z} - \dot{X}_e$

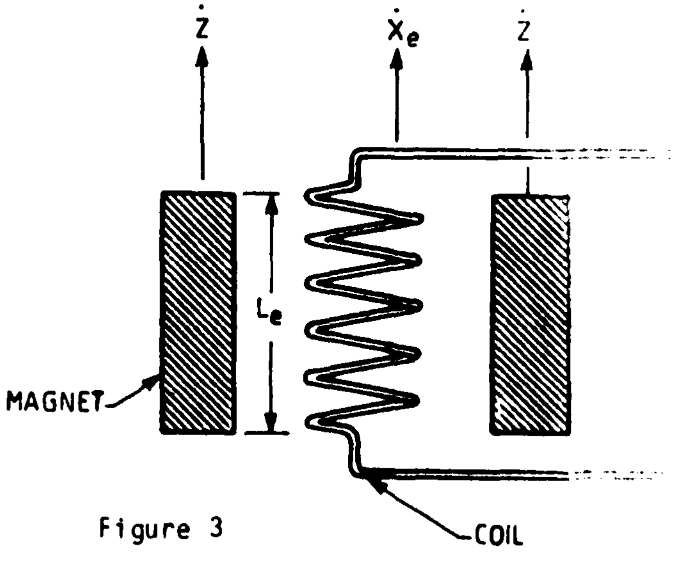


Figure 3

The heaving magnet body being part of the toroid float would follow the wave action readily making the phase angle $\sigma_z \approx 0$ and if motion is symmetric about the vertical axis then $\gamma = 0$ (Reference 1).

The circular frequency of the coil motion should be designed to be equal to that of the wave action

i.e. $$\omega_e = \omega$$

$$= \sqrt{\frac{K_e}{M_e}}$$

where K_e = spring constant

M_e = mass of coil system

A phase difference approaching 90° with the toroid float (magnet) motion leading the spar motion should be achievable by tailoring the design of the spar. Thus phase angle $\phi_e = -90°$ (Reference 2).

The condition for resonance thus becomes

$$\dot{\xi} = \omega(X_0 \cos \omega t - Z_0 \sin \omega t)$$

Electric Power $$P_e = \frac{N_e^2\, B_e^2\, L_e^2\, \dot{\xi}^2}{R_e}$$

N_e = No. of turns of wire coil

B_e = magnetic field

L_e - length of wire coil within magnetic field

R_e = load resistance in the wire coil.

Time Averaged Power

$$\hat{P}_e = \frac{1}{T} \int_0^T P_e \, dt$$

$$= \frac{N_e^2 B_e^2 L_e^2}{R_e} \frac{4}{T} \int_0^{T/4} \dot{\xi}^2 \, dt$$

$$= \frac{N_e^2 B_e^2 L_e^2 \omega^2}{R_e} \frac{4}{T} \int_0^{T/4} (X_0 \cos \omega t - Z_0 \sin \omega t)^2 \, dt$$

$$= \frac{N_e^2 B_e^2 L_e^2 \omega^2}{2R_e} \left(X_0^2 + Z_0^2 - \frac{4Z_0 X_0}{\pi}\right) \qquad \ldots . \ (1)$$

4. ESTIMATION OF POWER

Some idea of the maximum power can be estimated from equation (1) by substitution of typical values as in the following example

Wave period	T	-	2 sec
Wave frequency	ω	-	3.142 rad/sec
Length of coil	L_e	-	.101 m (4")
Magnetic field	B_e	-	.37 wb/m^2
Resistance	R_e	-	5 Ω
No. of turns	N_e	-	1000

Assuming an amplitude of magnet motion $Z_0 = .101$m

and for a stationary coil $X_0 = 0$

Then

$$\hat{P}_e = \frac{N_e^2\, B_e^2\, L_e^2\, \omega^2\, Z_o^2}{2R_e}$$

$$= 1378\ Z_o^2$$

$$= 14\ \text{Watts}$$

Assuming an amplitude of magnet motion Z_o = .303 m the variation of Power with coil amplitude is shown in Figure 4.

The efficiency of the system would be dependent on how much control of the damping for a particular design frequency was available. Apart from the viscous damping component there is also a magnetic damping component. Power obtained from a real ocean environment with random wave action would be more readily determined through field testing. A design frequency somewhere in the .5 to .1 Hz range (Fig. 5) would seem to be an appropriate starting point. The probability of average wave heights greater than .38 m is better than 95% (Fig. 6) which means that the magnet motion amplitude can be about .15 m (6").

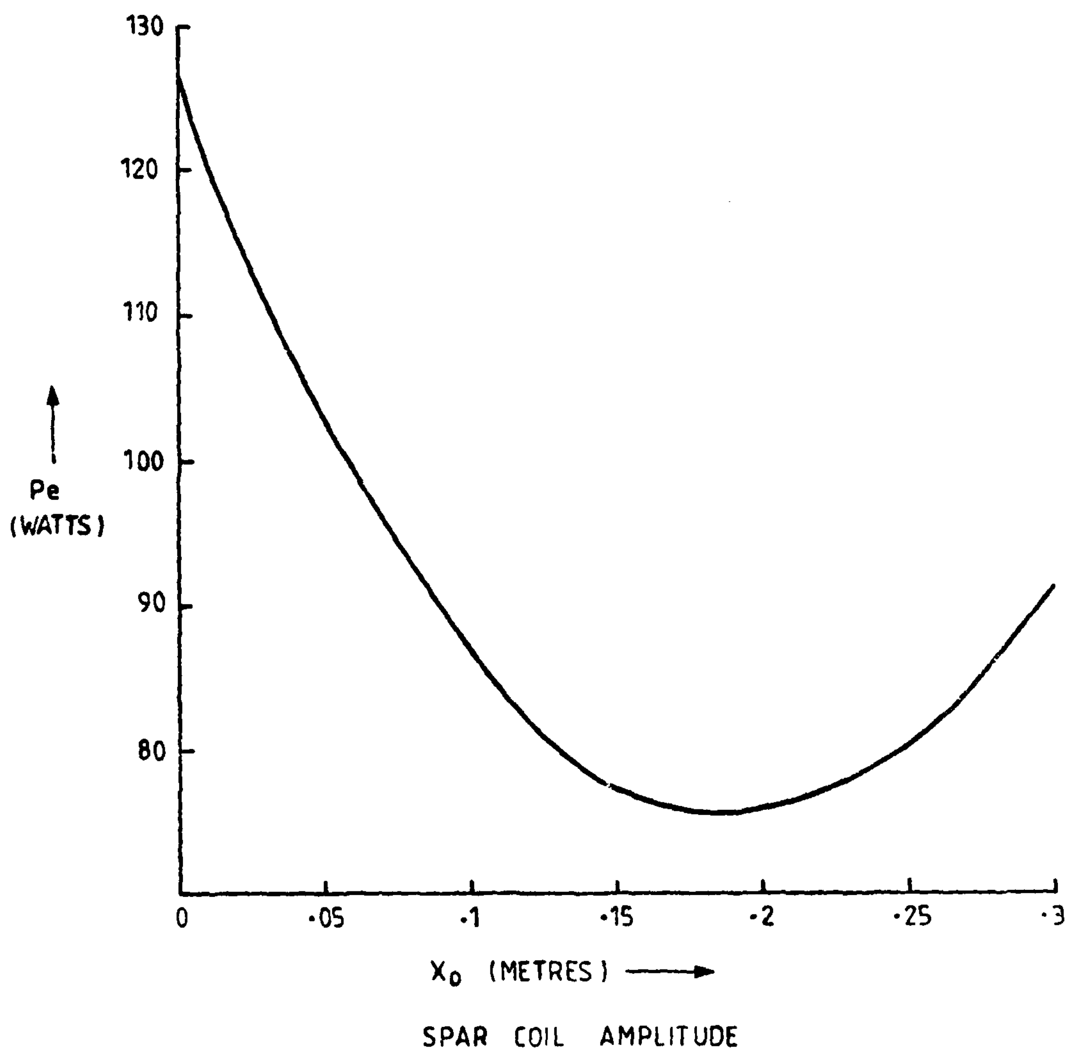

130
120
110
100
90
80
Pe
(WATTS)
0
·05
·1
·15
·2
·25
·3
X₀ (METRES)
SPAR COIL AMPLITUDE

Fig. 4.

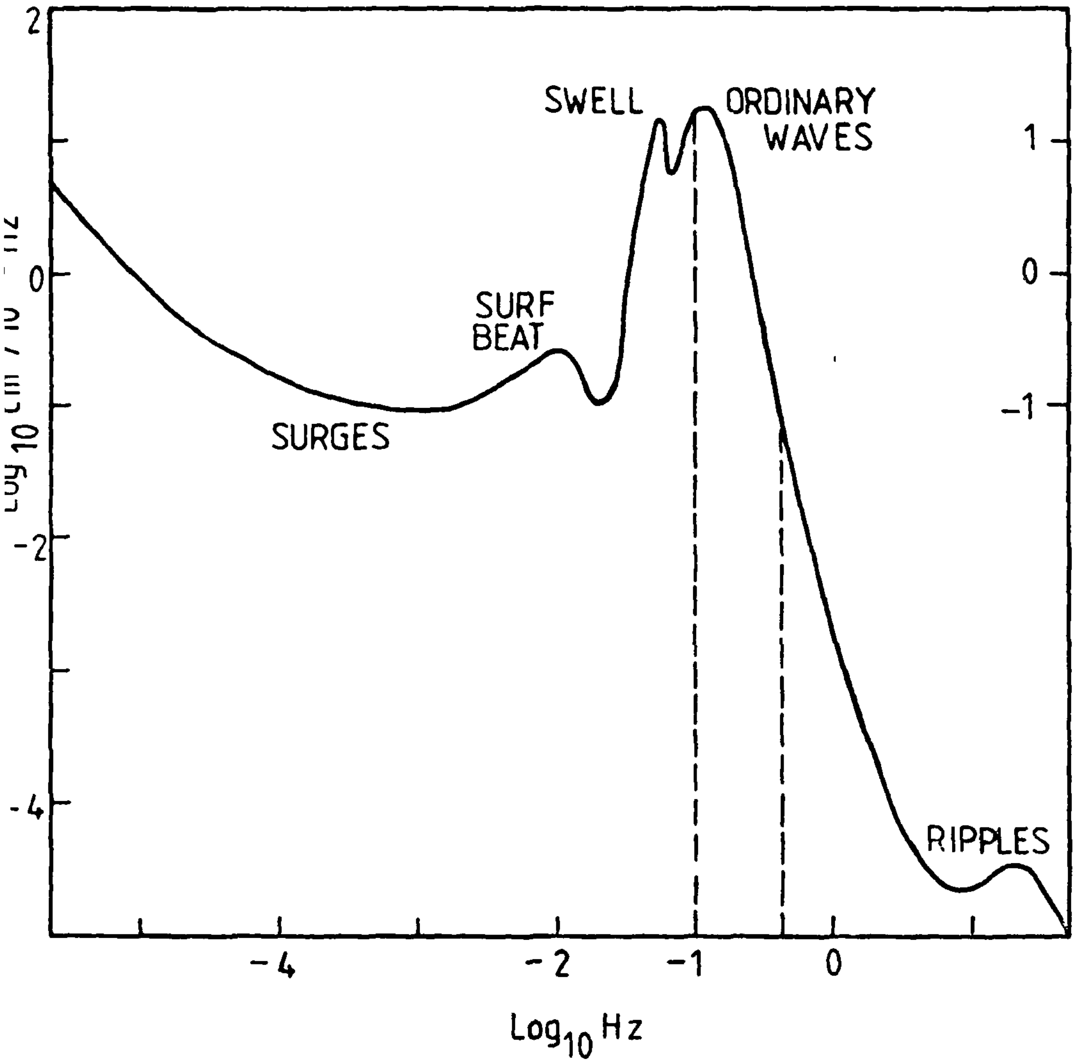
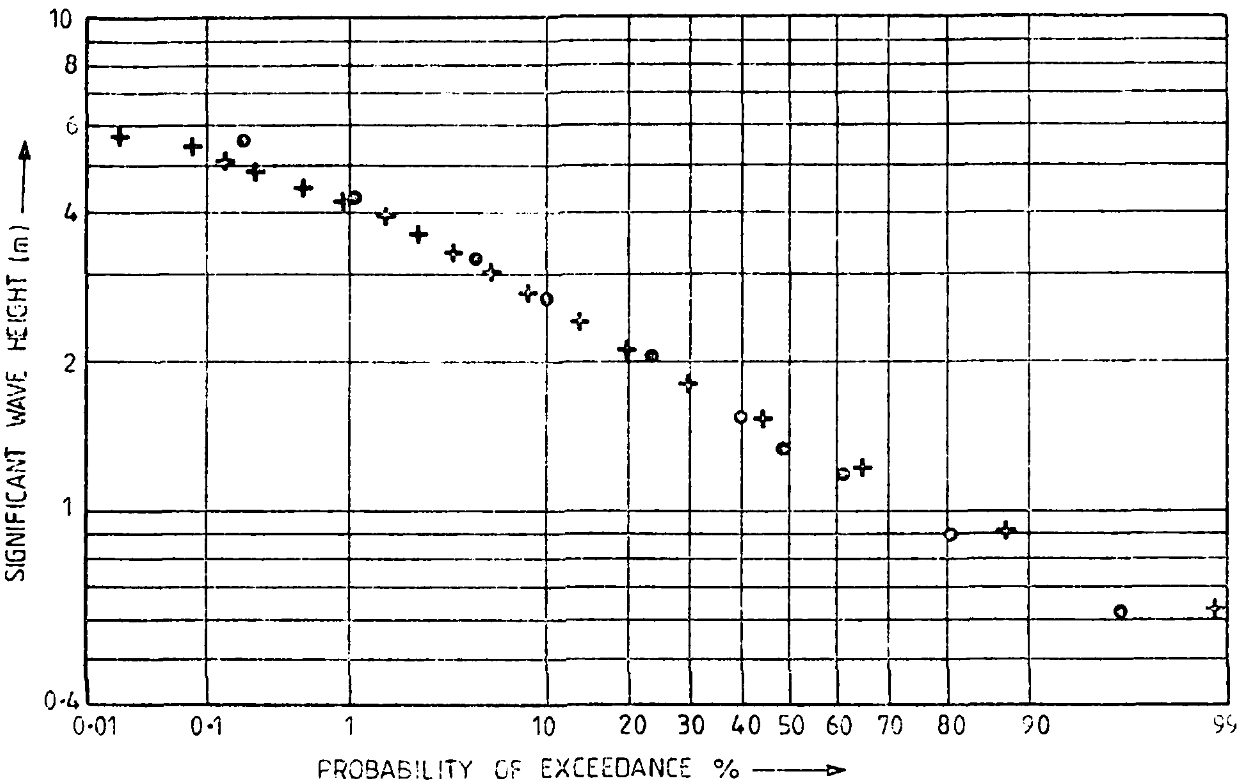
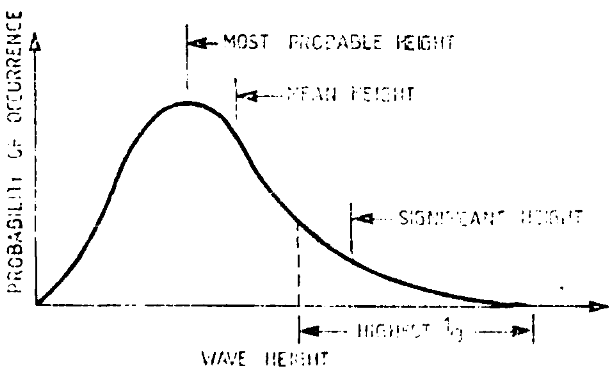


Fig. 5. Schematic plot of the ocean wave spectrum.





WAVE HEIGHT PROBABILITY DISTRIBUTION

RELATION OF WAVE HEIGHT PARAMETERS TO SIGNIFICANT WAVE HEIGHT.

SIGNIFICANT HEIGHT	1·00
AVERAGE HEIGHT	0·64
AVERAGE OF HIGHEST 10%	1·[illegible]
AVERAGE OF HIGHEST 1%	1·68
HIGHEST OF SIMPLE SINE WAVES HAVING SAME ENERGY CONTENT AS WAVE TRAIN	0·80

TABULATION BASED UPON CUMULATIVE RAYLIEGH PROBABILITY DISTRIBUTION

Fig. 6. The probability of exceedance of significant wave height : • present data
+ Lawson and Abernathy (1975).

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T. Omholt
Proceedings, "Oceans 78", Marine Technology Conference, Washington DC pp 585-589

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McGraw Hill, 1975

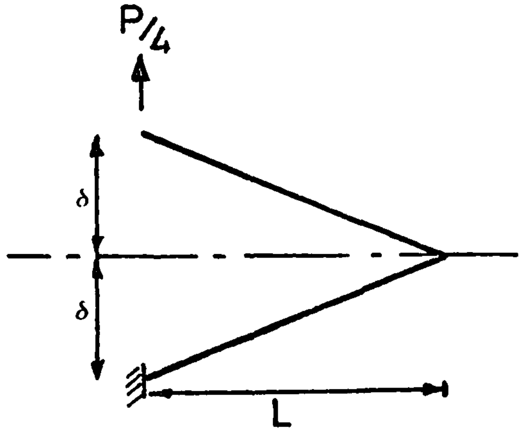
(5) Fig. 6 supplied by I.S.F. Jones
Ocean Sciences group, RANRL

APPENDIX

CALCULATION OF STIFFNESS OF SPRING SYSTEM AND MATCHING MASS

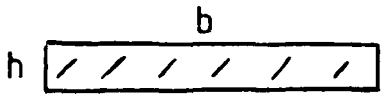
The load in the double cantilever spring system is distributed through four upper fingers and four lower fingers.

An estimation of the spar mass and the spring constant can be calculated from formulas in reference (4).



Example

If material is stainless steel sheet .10cm (.04") thick then E ≈ 206844 MPa (30x10 psi)
Section A-A(fig.2)



$$I = \frac{bh^3}{12} = 3.33 \times 10^{-4}\ \text{cm}^4\ (8\times10^{-6}\ \text{in}^4)$$

if

$$L = 30.5\ \text{cm}\ (12")$$

then stiffness K_e is given by $P = K_e\,\delta$

$$= 4\left[\frac{3EI}{(2L)^3}\right]\delta$$

i.e. $$K_e = \frac{3EI}{2L^3} = 36.5\ \text{n/m}\ (2.5\ \text{lb/ft})$$

if frequency $\omega_e = 3.142$ rad/sec

$$m_e = K_e/\omega_e^2$$

$$= 3.63\ \text{kg}\ (8\ \text{lb mass})$$

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2003
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16. Abstract

THE MOTION OF A BUOY SYSTEM MADE UP OF A SPAR AND TOROID FLOAT IS USED TO DRIVE A LINEAR INDUCTION GENERATOR. (U)

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